FEM Analysis of Pressure-tight Ceramic Housings with Metal Caps

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***Abstract*— We propose a new simple design method for a ceramic pressure-tight housing with metal caps. Ceramics have higher compressive strength and lower specific gravity than typical metals. Moreover, they are free from erosion by seawater. For that reason, we can produce light pressure-tight ceramic housings that have good durability for deep-water applications. The proposed ceramic housings have greater buoyancy than metal housings. We conducted finite element analysis (FEA) and confirmed its validity. We are now preparing hydraulic pressure tests using small ceramic housings with metal caps.**

Keywords—Ceramic; Pressure-tight housing; metal caps; ceramic cylinder

I. INTRODUCTION

We propose a new simple design method of a ceramic pressure-tight housing having metal caps. We conducted finite element analysis (FEA) and confirmed its validity.

Ceramics, as presented in Fig. 1, have higher compressive strength and lower specific gravity than typical metals do. Moreover, they are free from erosion by seawater. For that reason, we can produce light pressure-tight ceramic housings with good durability for deep water applications. Moreover, we can reduce the amount of additional expensive syntactic foam when applied to underwater vehicles that require neutral buoyancy. Because they are nonmagnetic and insulating materials, they are suitable for housings of electromagnetic sensors. However, common design methods cannot be used for ceramic pressure-tight housings because the tensile strengths of ceramics are only a fraction of the compressive strength, as presented in Fig. 1.

Stachiw [1] conducted a series of vigorous studies of ceramic pressure-tight housings from 1961. His work led to development of 3.6-inch and 10-inch ceramic flotation spheres for use in deep sea applications [2], [3], and a ceramic pressure-tight housing for use on an 11 km water depth hybrid underwater vehicle: NEREUS [4]. We developed ceramic sphere housings for ocean-bottom seismometers used in deep ocean applications [5], and developed small ceramic housings having cylindrical fuselages [6].

Usually, through-holes are necessary for underwater connectors on the pressure housings. However, stress concentrations of about double that which appears around through-holes make their design and fabrication complex when

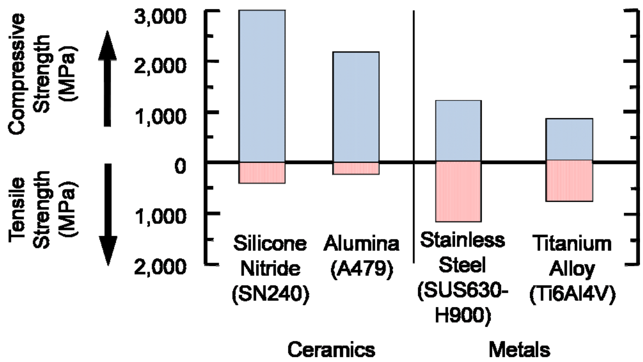


Fig. 1 Strengths of ceramics and metals.

ceramics are used as materials. This issue can be avoided by adopting metal caps, but differences in displacements caused by hydraulic pressure at contact faces between metal caps and ceramic cylinders are expected to produce tensile stress in ceramic cylinders. We must reduce this tensile stress because the tensile strengths of ceramics are only a fraction of their compressive strength, as described above. We have addressed this issue by adding ribs to the metal caps to equilibrate the displacement of metal caps and the ceramic cylinder. We evaluated the method's validity using FEA.

As described in this paper, we present the results of FEA.

II. FEA ANALYSES

A. Model for FEA

Fig. 2 presents a cross section view of the model for FEA. Sealing between metal caps and the ceramic cylinder is performed using self-bonding rubber. Because caps are made of metals, the design and fabrication of through-holes on them for underwater connectors is easy. Alumina ceramic (A479; Kyocera Corp.) was used for the ceramic cylinder and aluminum alloy (A7075-T6) was used for the metal caps. The Young's modulus, Poisson's ratio and specific gravity of the A479 alumina ceramic are, respectively, 360 GPa, 0.23, and 3.8.

The buckling pressure P_k for thin cylinders of unlimited length and can be expressed as

$$P_k = \frac{E_c}{4(1-\nu_c{}^2)}\left(\frac{t_c}{r_c}\right)^3 \quad (1)$$

where

Ec:	Young's modulus of the cylinder
ν_c:	Poisson's ratio of the cylinder
r_c:	radius of the cylinder
tc:	thickness of the cylinder

The thickness of the cylinder can be expressed as (2).

$$t_c = r_c\left(\frac{4(1-\nu_c{}^2)}{E_c P}\right)^{1/3} \quad (2)$$

Assuming P and r_c of 60 MPa and 50 mm respectively, t_c becomes 4.48 mm. We adopted the thickness of 4.5 mm, inner radius of 50 mm, and length of 100 mm for the cylinder because the buckling pressures for cylinders of finite lengths are higher than those for unlimited length cylinders. The hoop stress on the cylinder $\sigma_{\theta c}$ (670 MPa), which is given by (3), is much lower than the compressive strength.

$$\sigma_{\theta c} = \frac{r_c}{t_c}P \quad (3)$$

The hoop stress on thin hemispheres $\sigma_{\theta s}$ can be expressed as

$$\sigma_{\theta s} = \frac{r_s}{2t_s}P \quad (4)$$

where

r_s:	radius of the hemisphere
ts:	thickness of the hemisphere

The thickness of the hemisphere is given as (5).

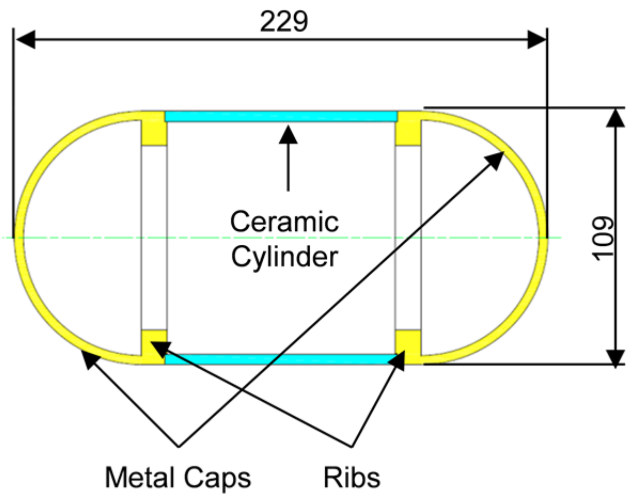
$$t_s = \frac{r_s}{2\sigma_{ys}}S_F P \quad (5)$$

Where

σ_{ys} :	yield strength of the material
S_F :	safety factor

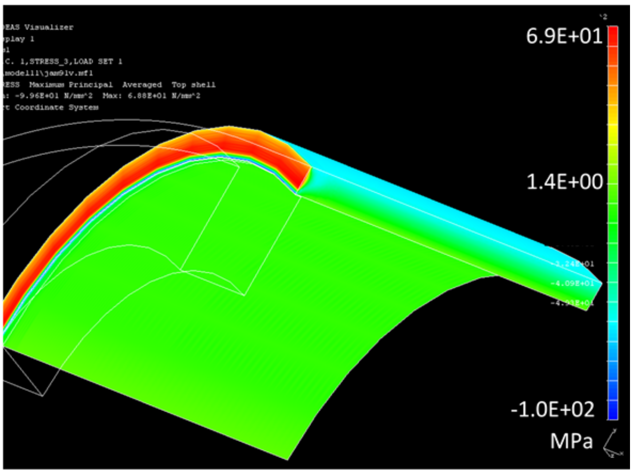
We adopted the same outer radius of 54.5 mm as that for the cylinder. Using the safety factor of 1.1, the thickness of the hemisphere t_s becomes 3.9 mm. The buckling pressure is higher than 60 MPa for the hemisphere. Young's modulus, Poisson's ratio, specific gravity and the yield strength of the aluminum alloy (A7075 T6) are, respectively, 71.6 GPa, 0.345, 2.8, and 505 MPa .

To reduce the difference between the displacement of the metal hemisphere and the ceramic cylinder at the contact face,

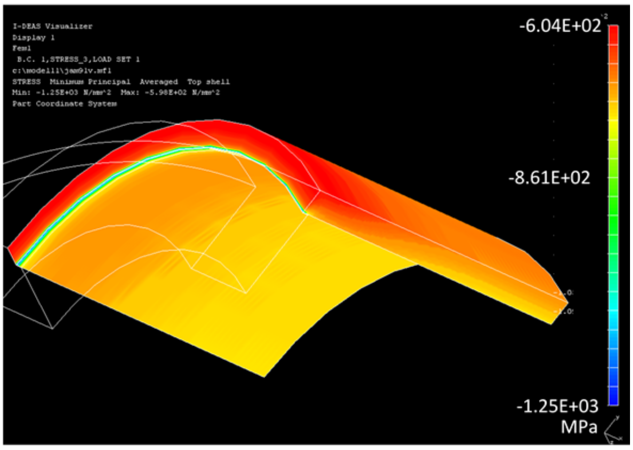


unit: mm

Fig. 2 Cross section view of the model for FEA.



(a) Minor Principal Stress



(b) Major Principal Stress

Fig. 3 Example of FEA results. The contour of the principal stresses on the contact-surface of the ceramic cylinder is shown.

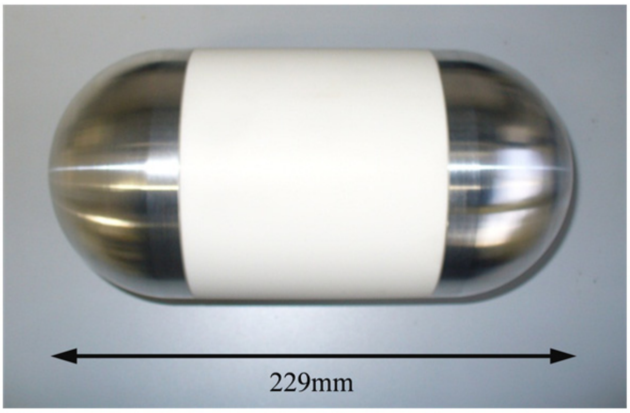


Fig. 4 A small ceramic pressure-tight housing with metal caps for hydraulic tests.

and to reduce the tensile stress generated by the difference above, we added a rib at the inside of the hemisphere, as presented in Fig. 2.

The respective weight and volume of the housing are 1.32 kg and 1.8 l. The housing can provide positive buoyancy even at water depth of 6,000 m.

B. *Results of FEA*

Fig. 3 presents an example of the FEA results of the ceramic cylinder. Making use of symmetry, we analyzed only one-fourth of the model. Fig. 3 shows that the respective peak values of the major and the minor principal stress on the ceramic cylinder are 60 MPa and -1,250 MPa. They are lower than the rated tensile strength (166 MPa) and the rated compressive strength (2,160 MPa) of the material.

III. Hydraulic Test

We produced small pressure-tight ceramic housings with metal caps portrayed in Fig. 4. We are now preparing hydraulic pressure test using these housings.

IV. Concluding Remarks

We proposed a new simple design method of a ceramic pressure-tight housing having metal caps. We conducted finite element analysis (FEA) and confirmed its validity. We then made pressure-tight ceramic housings with metal caps. We are now preparing hydraulic pressure tests using small ceramic housings with metal caps.

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